Computational Analysis of Imagined Speech Electroencephalogram: A Neuroscience Perspective

Abstract

For most individuals, speaking is the most natural form of communication, often disrupted by damage to the brain or the vocal centers. As language processing involves synapses in the brain that can be measured as electrical signals using electrodes, these signals can be converted into synthetic speech. The most common brain activity recording modality for brain-computer interfaces (BCIs) is the electroencephalogram (EEG), which is wearable and portable. However, decoding EEG signals of imagined speech is challenging due to the complexity of language and poor signal-to-noise ratios. Current methods focus primarily on decoding imagined speech EEG while neglecting the identification of neural correlates of language. This thesis seeks to address this gap through several experiments. The first experiment is a pilot study using a sliding-window approach to segment EEG epochs into smaller fragments. By analyzing these fragments for classification, a notable improvement was observed over using entire epochs, indicating that imagined speech information is temporally localized. A parallel experiment assessed static features for their viability as indicators for an asynchronous BCI, revealing that features derived from first-order derivatives were particularly important. The second experiment used resting-state EEG signals to estimate the duration of imagined speech events, which were then combined with a hybrid neural network comprising long short-term memory and convolutional neural network layers, along with saliency maps, to localize informative segments. The third experiment applied saliency maps to explore if similar-sounding words produced similar EEG patterns. By using a modified spectro-temporal EEGNet, heatmaps were compared across tasks, revealing statistically significant similarities in EEG regions important for encoding these words. The final experiment involved an end-to-end Deep Learning classifier, SincTran, which analyzes the spectral decomposition of imagined speech. Its results support findings from the previous experiment, showing similar geometries for similar-sounding words. These experiments advance understanding of the neural correlates of language and enhance the potential of BCI for individuals with speech disorders by illuminating the unique characteristics of imagined-speech EEG signals.

Keywords: Imagined speech, Brain-computer interface, Computational neuroscience, Explainable artificial intelligence, Electroencephalogram signal analysis